ONR Basic Research in Ocean Acoustics for FY05

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LONG-TERM GOALS

The long-term goals of this research are [1] to advance the experimental and theoretical knowledge base for the interaction of low frequency sound with the seabed in complex shallow water environments and [2] to characterize the nature of ambient noise in a deep water region. The primary goal for the shallow water research is the discovery by experimentation of the underlying physics for the frequency dependence of the complex sound speed in marine sediments typically found in shallow seas. The primary goal for the ambient noise research is the recovery, analysis, and interpretation of acoustic data collected at a submerged buoy site in the Northeast Pacific Ocean.

OBJECTIVES

There were five objectives of the research for FY05.

1. Fabricate two L-arrays for the planned Shallow Water Acoustic 2006 Experiment (SW06) off the New Jersey continental shelf and upgrade the electronics of two Shallow Water Acoustic Measurement Instrumentation (SWAMI) data acquisition systems.

2. Inclusion of frequency dispersion effects into geo-acoustic inversion methodology.

3. Initiate calibration studies for impulsive sources to be used for SW06 experiment.

4. Complete theoretical study on the separation of forward and backscattering energy in inhomogeneous media.

5. Complete ambient noise analysis of deep ocean acoustic measurements in the Northeast Pacific Ocean. Note that this work was done in collaboration with Dr. Roy Gaul of BlueSea Corporation Contract number N00014-05-M-0027.

APPROACH

1. Equipment fabrication and upgrades

The two L-arrays are 350 meters in length. One has 32 hydrophones and the other 52 hydrophones. For each array, the vertical segment that spans the water column has is about 65 meters in length. The horizontal segment of each array is about 270 meters. The horizontal components of the 52-element and 32-element arrays are optimized for the 25-1000 Hz and the 25-3000 Hz bands, respectively. Each

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14. ABSTRACT
The long-term goals of this research are [1] to advance the experimental and theoretical knowledge base for the interaction of low frequency sound with the seabed in complex shallow water environments and [2] to characterize the nature of ambient noise in a deep water region. The primary goal for the shallow water research is the discovery by experimentation of the underlying physics for the frequency dependence of the complex sound speed in marine sediments typically found in shallow seas. The primary goal for the ambient noise research is the recovery, analysis, and interpretation of acoustic data collected at a submerged buoy site in the Northeast Pacific Ocean.

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array is connected to a SWAMI system package that rests on the seafloor. The two SWAMI systems are essentially identical, but with different anti-aliasing filters for the different bandwidths. The array designs are based in part on the anticipated water depth at the planned SW06 location, lessons learned from other geo-acoustic inversion studies, and the experimental objectives.

2. Inclusion of frequency dispersion effects into geo-acoustic inversion methodology

Possible seabed representations for broadband inversion of low frequency transmission loss and/or time series data are expanded to allow for frequency dispersion of the complex sound speed in inhomogeneous sediment layers. Several Kramers-Kronig dispersion relationships and a modified Biot parameterization are included into an inversion methodology based on simulated annealing and a forward propagation model based on normal mode theory [1].

3. Calibration of impulsive sources

Calibration studies of sources to be used in the SW06 experiment are conducted at the Lake Travis Testing Station (LTTS), Applied Research Laboratories, The University of Texas at Austin (ARL:UT). Impulsive and explosive sources are activated in the deepest section of the lake and two calibrated hydrophones record the received signals. The signals are separated into direct and boundary reflected arrivals. Knowledge of the geometry of the source and receivers allows for the primary characteristics of the impulsive waveforms to be determined from the measured data. Such characteristics are the time interval from implosion to peak level (bubble time), the peak pressure, the energy spectral density (ESD) level, the frequency and level at the peak ESD, the energy source level (ESL), and the total emitted energy.

4. Separation of forward and back scattered energy in inhomogeneous waveguides

The integral equation form of the coupled mode equations is modified to separate in a meaningful manner forward- and back-propagating components of the acoustic field. Such a separation is made possible by the boundary conditions implemented directly into the free Green's function and its unique separation into forward and backward propagators. In addition a perturbation approach is used to generate a forward going propagation model that is an alternative to the Foldy-Wouthuysen approach [2].

5. Ambient noise analysis

The methodology adopted in this research is to analyze acoustic data (from CHURCH OPAL experiment) collected on a hydrophone below the critical depth of the sound speed profile for the purpose of separating, as much as possible, the noise components due to residual long-range shipping and wind. Time intervals are selected from the 10-day data set that are approximately free of near- and medium-field shipping noise, biological noise, certain types of man-made events, and internal system noise. Using inferred wind speeds, the average values and the higher moments of the ambient noise as a function of wind speed and frequency are quantified. These analyses then allow for a meaningful proposed modification of the Wenz curves.

Key personnel in this research include Dr. David Knobles (Research Scientist), Mr. Lewis Thompson (Project manager of Environmental Sciences Laboratory Engineering Group), Dr. Robert Koch (Research Scientist Associate), Mr. Thomas Novaln (Undergraduate Student in Electrical Engineering), Mr. Shaun Sherman (Summer High School Apprentice), and Mr. Jack Shooter (Research

Engineering Scientist). This work was done in collaboration with Dr. Roy Gaul of BlueSea Corporation Contract number N00014-05-M-0027.

WORK COMPLETED

Work that was completed in FY05 include:

1. Array designs for both L-arrays have been finalized and the major equipment has been delivered. Currently, the arrays are being assembled and the electronics of both SWAMIs are being upgraded.

2. Effects of frequency dispersion of the complex sound speed in marine sediments were incorporated into an analysis of broadband transmission loss data taken in the East China Sea [1].

3. Light bulbs were calibrated at the LTTS. Functional form of energy source level (ESL), total emitted energy, and other characteristics of light bulb implosions were established as a function of bulb volume [3]. A similar test is planned for a combustive sound source.

4. It was demonstrated that forward and backward components of the acoustic field in inhomogeneous media can be separated in a meaningful manner within the framework of an integral equation approach.

5. Ambient noise analysis for deep water data set is complete and a manuscript is being prepared for the IEEE Journal of Oceanic Engineering.

RESULTS

1. Array fabrication and SWAMI electronics upgrades

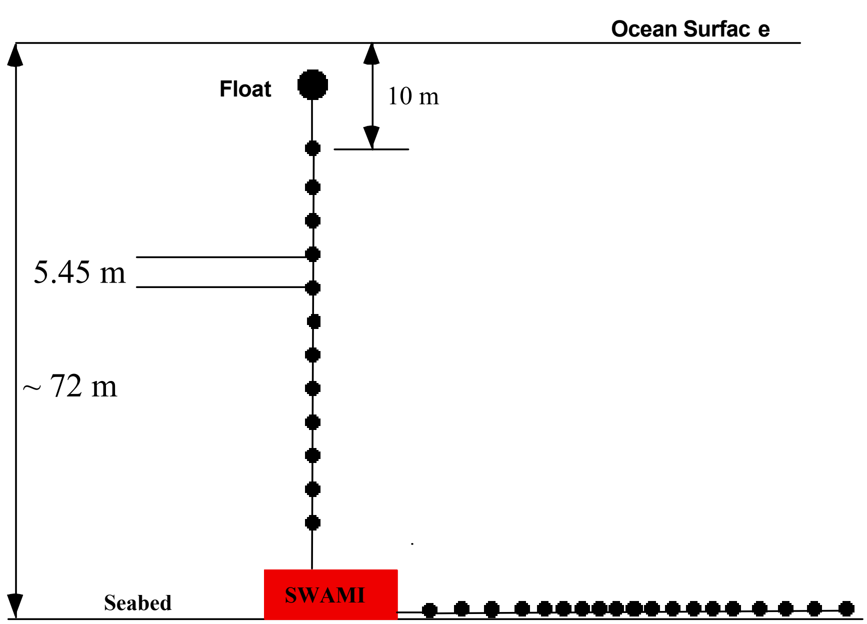

Figure 1: Design of 32-element L-array for SW06.

Figure 1 shows the array design for one (32-channel SWAMI) of two L-arrays currently under construction for the SW06 experiment. The vertical portion of the array has 12 equally spaced hydrophones and covers about 60 meters of the water column (about 72 meters). The horizontal component is about 290 meters in length with 20 hydrophones in a symmetric, center tapered configuration. The 52-element array will also have 12 elements for the vertical component but have 40 elements for the horizontal component. The horizontal component of the 52-element L-array is also in a symmetric, center tapered configuration. The sampling rate for the 52-channel and 32-channel SWAMIs are about 2400 and 6000 Hz, respectively. The array designs reflect balances of basic broadband designs for signal processing and for geo-acoustic inversion.

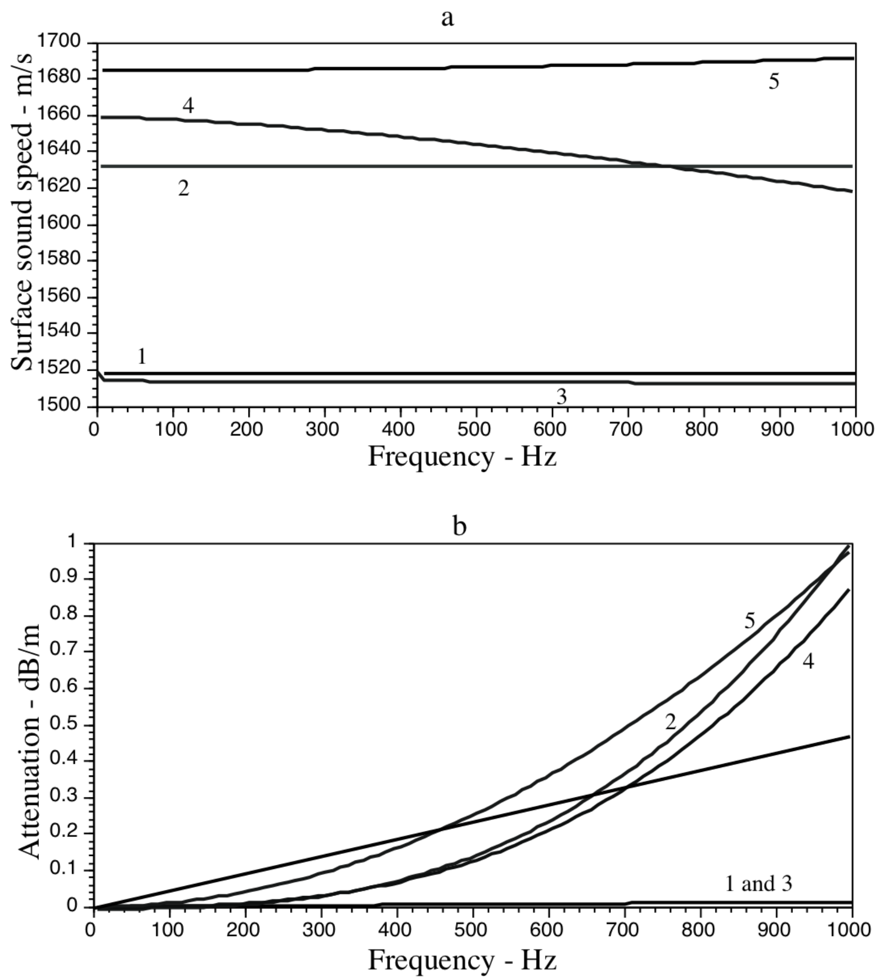

Figure 2: Frequency dispersion of sound speed and attenuation of first sediment layer from inversion of broadband transmission loss data from East China Sea. [1] No sound speed dispersion and attenuation linear with frequency, [2] No sound speed dispersion with attenuation non-linear with frequency, [3] Attenuation linear with frequency and sound speed obeying Kramers-Kronig dispersion relationship, [4] Attenuation non-linear with frequency and sound speed obeying Kramers-Kronig dispersion relationship, and [5] Sound speed and attenuation constrained with 6-parameter Biot approximation.

Figure 2 shows the result of an application of geo-acoustic inversion to octave average transmission data collected in the East China Sea [1]. Five possible seabed representations were assumed in the inversions. A linear frequency dependence of the attenuation in the 25-800~Hz band, with or without sound speed dispersion, leads to a geo-acoustic solution using the TL data consistent with a soft clay and inconsistent with the existing geophysical data. However, seabed representations that allow for a non-linear frequency dependence of the attenuation, such as a Kramers-Kronig dispersion relationship, a simplified 6-parameter Biot description, and an empirical frequency power law of the attenuation all give similar values of the attenuation as a function of frequency and sediment sound speeds that are consistent with the previous geophysical studies in the area.

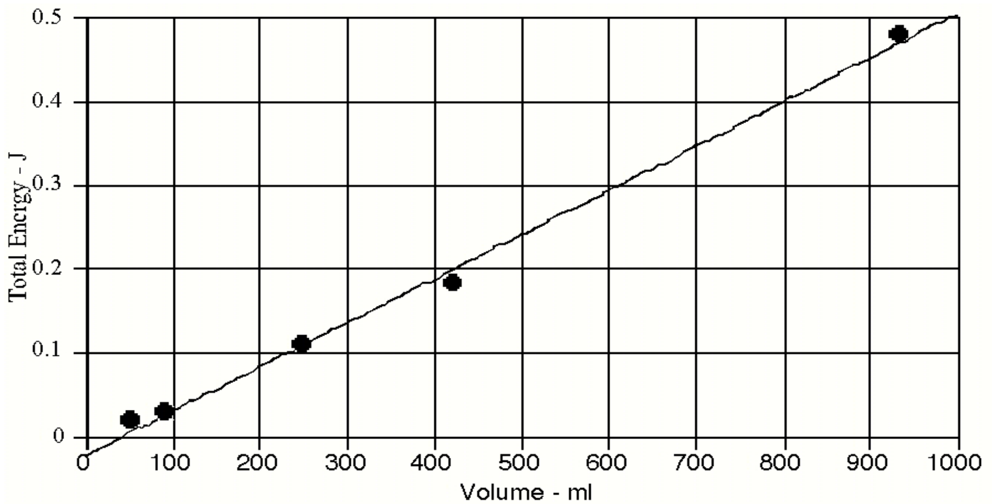

Figure 3: Total energy versus bulb volume for source depth of 25 m.

A large sample of light bulbs were used in an experiment at the LTTS ARL:UT to determine the emitted source properties of light bulbs as a function of their volume. The selected lightbulbs were G-series that had a nearly spherical shape. The interval of bulb volume was about 50-1000 ml. Figure 3 shows the calculated total energy as a function of bulb volume. Each point represents about ten samples. The experimental uncertainty was about 0.005 J at 50 ml and increased to about 0.05 J at 1000 ml. There is a linear relationship between total emitted energy and bulb volume. It is interesting to note that the total ambient potential energy of the implosion is proportional to the product of the difference pressure (ambient water pressure minus internal bulb pressure) and the effective bulb volume of the bubble. This says that in spite of known damping effects, a linear increase in the ambient potential energy with volume results in a linear increase of the total emitted sound energy with bulb volume.

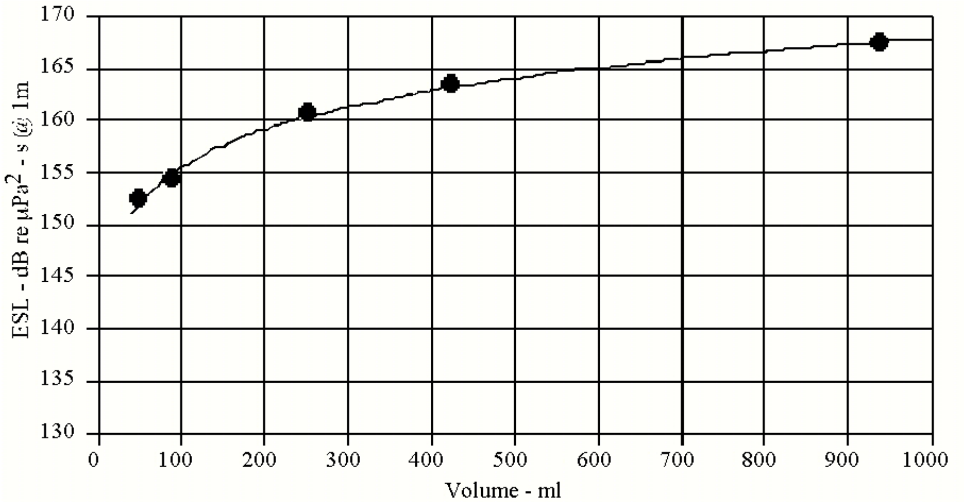

Figure 4: Energy source level (ESL) for light bulb implosion versus bulb volume for source depth of 25 m.

Figure 4 shows the measured energy source level (ESL) [4] as a function of bulb volume. The blue line is a best fit curve for the measured data. The largest uncertainty is about 2 dB. One observes levels on the order of 155 dB for bulb volumes around 100 ml and 168 dB for bulb volumes around 1000 ml. Clearly, in terms of dBs the rate of return for increasing bulb volume is limited.

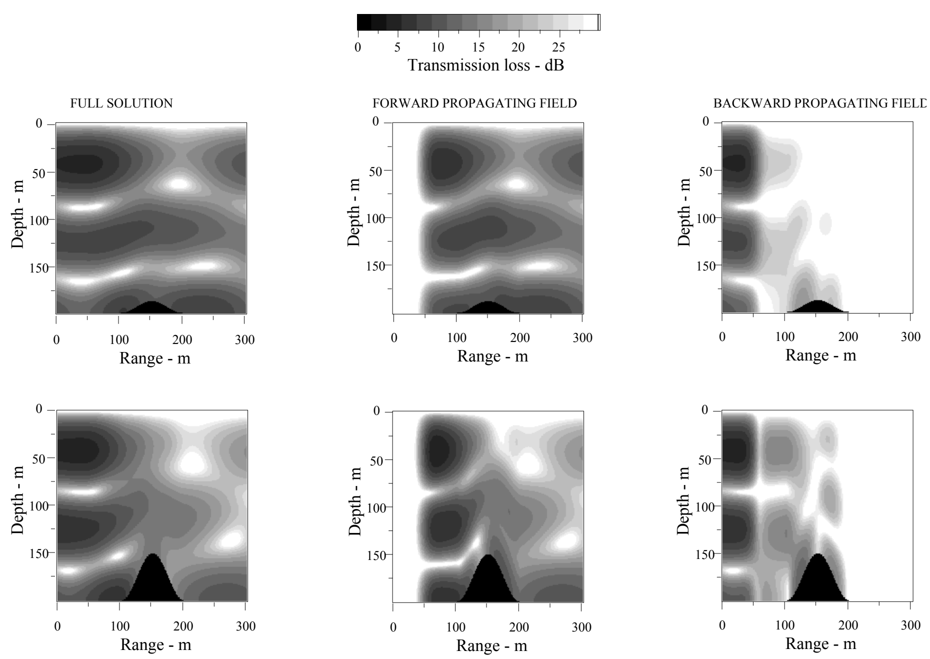

Figure 5: Separation of acoustic field into forward and backward components.

Figure 5 shows the acoustic field for a 2-D waveguide where the bathymetry has the shape of a Gaussian "hill." The propagation frequency is 10 Hz and the source depth and source range are 50 m and –100 m, respectively. The integral equation formalism in [5] was modified to explicitly allow for the separation of the forward- and backward-propagating components of the acoustic field. The backward going components have two contributions. One is the backward-propagating component present in the asymptotic region as x goes to negative infinity and the second is backscattering that results from multiple scattering which also contributes to the forward propagating component in the asymptotic region as x goes to positive infinity. It is important to note that the forward-propagating component has corrections to all orders for the effect of the backward-propagating components. The next step is to compare a recently introduced method that obtains the forward component via a perturbation approach [6] that differs from the Foldy-Wouthuysen method [2].

Figure 6 shows averaged measured ambient noise as a function of frequency for wind speeds (WS) in the range of 0-20 knots on the 4850 m hydrophone. From $0 \leq$ WS ≤ 15 knots one observes a minimum value for the ambient noise as a function of frequency. For WS ≤ 5 knots, the minimum occurs at 200 Hz and is about 40 dB. At 7.5 knots the minimum occurs at 150 Hz. For $7.5 $\geq$WS $\geq$ 15 knots, the minimum occurs at about 100 Hz. Starting at 15 knots the minimum appears to shift to a value below 50 Hz. For frequencies above the minimum value, one observes an increasing ambient noise level with increasing frequency up to 500 Hz. For frequencies below the minimum value one observes an increasing ambient noise level with decreasing frequency down to about 50 Hz. One can ascribe these observations to competing factors of wind noise and residual long-range shipping. For example, for WS < 5 knots the observed noise above 200 Hz is dominated by wind. In the 10-200 Hz range, the noise due to residual shipping becomes greater than that associated with wind. In short for a given frequency the minimum of the ambient noise occurs at the frequency where the wind and residual shipping components of the noise are approximately equivalent. This is the reason for the minimum structure for WS < 15 knots.. This minimum shifts to lower frequencies as the WS increases up to about 15 knots. For WS $\geq$ 15 knots, the residual shipping no longer makes the dominant contribution even in the frequency band of 30-80 Hz where shipping source levels are highest. Thus for 15 knots and above the ambient noise is characterized as wind saturated above about 20 Hz. This is the physical basis for the behavior observed in Fig. 6.

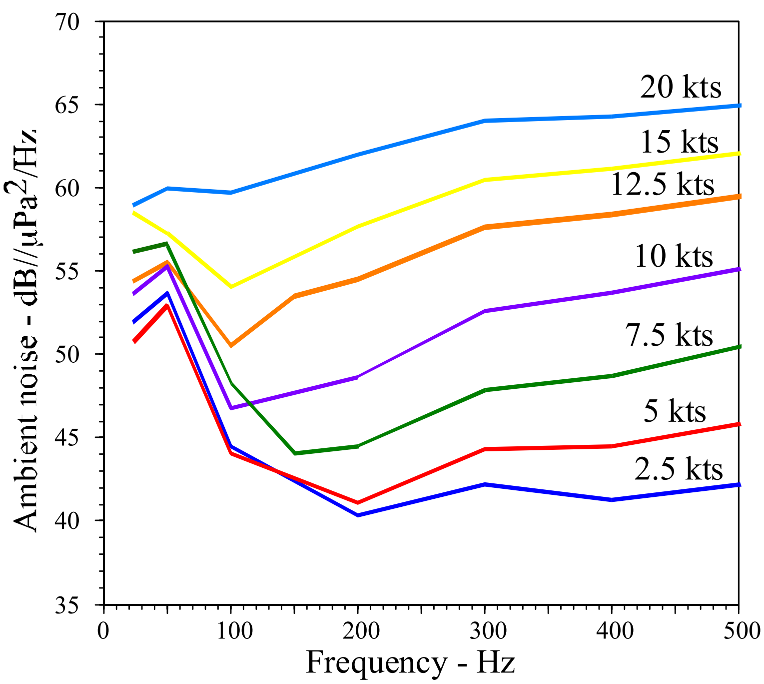

Figure 6: Average values of ambient noise as a function of frequency and wind speed

IMPACT/APPLICATIONS

The academic impact of the shallow water studies is that they have aided in identifying the required measurements for future experiments that can advance the knowledge base of the physics of dispersion in marine sediments and scattering in the seabed below 1000 Hz. The potential applied impact of these studies includes the advancement of methodologies that can simultaneously infer the environment and localize sources of interest for both passive and active systems. The ambient noise analyses have allowed for the quantification of the wind component of the ambient noise below 500 Hz in a deep water region. Further, the residual shipping component has also been quantified.

TRANSITIONS

A transition of this research is that the expanded knowledge base for seabed acoustics that results from the SW06 experiment can be applied in emerging geo-acoustic inversion capability. Further, the theoretical scattering studies may aid in the development of efficient reverberation models for littoral regions. Another transition is new funding to recover acoustic data from other Long Range Acoustic Propagation Project data sets.

RELATED PROJECTS

Related projects to the current research includes geo-acoustic inversion methods and reverberation studies funded by the Navy.

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